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PHYSICAL DISABILITIES AND COMPUTING TECHNOLOGIES: AN ANALYSIS OF IMPAIRMENTS

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INTRODUCTION

Computing devices are becoming smaller, more mobile, more powerful, and less expensive. As a result, they are making their way into every aspect of our lives. Although computing devices can be convenient tools for traditional computer users, they can also serve as barriers for individuals with impairments. A design process that considers the impairments of potential users can turn these barriers into powerful tools that increase employment opportunities, provide enhanced communication capabilities, and enable increased independence (Young, Tumanon, & Sokal, 2000).

Cognitive, perceptual, and physical impairments (PIs) can all hinder the use of computing technologies, but the focus of this chapter is on specific physical impairments that contribute to disability. More specifically, we focus on PIs that may hinder an individual's ability to physically interact with computing technologies (e.g., PIs affecting the upper body). Therefore, we do not address PIs that affect the lower body or hinder the production of speech. For additional information regarding cognitive or perceptual impairments, see chapters 24 and 26, respectively. Chapters 21 and 22 may also provide useful insights because they address the issues involved in designing technologies for elderly users and children, two groups whose cognitive, perceptual, and physical capabilities may require special attention.

The objectives of this chapter are to

- provide an introduction to specific PIs that can hinder the use of traditional computing devices,
- highlight critical characteristics of these PIs that must be considered when designing computing systems,
- discuss the relationship between PIs that result from health conditions and those that result from environmental or contextual factors,
- summarize the results of existing human–computer interaction (HCI) research involving individuals with PIs, and
- offer observations based on the literature that may provide guidance for future research and development efforts.

We believe that by beginning with an understanding of the PI involved, it is possible to design computing technologies that lessen or even eliminate the associated disabilities. We begin by presenting a set of definitions for *impairment*, *disability*, and *handicap* that are offered by the World Health Organization (WHO). By formally defining these terms and using the terms in a way that is consistent with these definitions, we hope to eliminate potential ambiguity and confusion. Subsequently, we define the subset of PIs that are of primary concern when addressing an individual's ability to physically interact with computing technologies. Through this definition, we further clarify the scope of this chapter.

Given these definitions, we proceed to discuss the relationship between health conditions and PI. Understanding the underlying health condition is critical because this often provides valuable insights into the nature of the resulting impairment. In this context, we describe common health conditions (e.g., cerebral palsy, spinal cord injuries) associated with PIs that can hinder an individual's ability to interact with computing devices. We identify the associated PIs, their important characteristics, and any additional impairments that may prove critical when designing computing technologies. Although health conditions are most often associated with PIs, both contextual and environmental factors can also hinder interactions with computing devices. As a result, we briefly discuss the relationship between the environment, context, physical impairments, and disabilities. Through this discussion, we highlight critical similarities and differences between those PI that result from health conditions and the difficulties individuals may experience as a result of the environment or activities in which they are engaged.

We conclude by reviewing recent research that has focused on addressing the needs of individuals with PI, discuss existing technologies in the context of various PI, and offering directions for additional research.

DEFINING IMPAIRMENT

WHO first published the International Classification of Impairments, Disabilities, and Handicaps in 1980. The final draft of the second version of this document (ICIDH-2) provides a set of definitions that serve a foundation for this our discussion (WHO, 2000). The ICIDH-2 model acknowledges the complex relationships that exist among health conditions, impairments, disabilities, and handicaps. This model also highlights the potentially important role of both the context and environment in which activities are taking place. Figure 25.1 highlights the relationships between impairments, disabilities, and handicaps as well as the influence of both health conditions and context. Both health conditions and context can directly result in impairments, disabilities, or handicaps. Contextual factors (e.g., environment and tasks) can also affect the relationship among impairments, health conditions, and handicaps. For example, a specific impairment may or may not result in a disability, depending on the environment in which the individual is located and the tasks in which the individual is engaged.

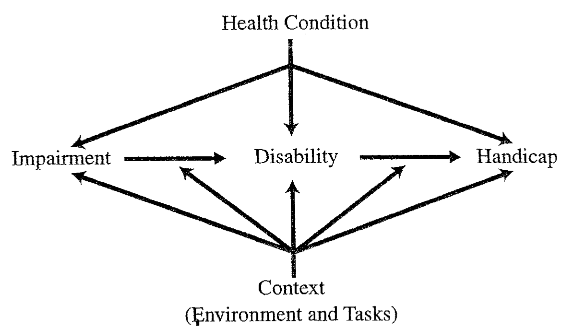

FIG. 25.1. Model illustrating the relationship between health conditions, disabilities, impairments, handicaps, and contextual factors.

The following definitions are adapted from the ICIDH-2:

- *Health condition:* A disease, disorder, injury, or trauma. Examples include spinal cord injuries, arthritis, cerebral palsy, stroke, multiple sclerosis, and amyotropic lateral sclerosis.
- *Impairment:* A loss or abnormality of body structure or function. Examples of physical impairments include a loss of muscle power, reduced mobility of a joint, uncontrolled muscle activity, and absence of a limb. Impairments can be caused by health conditions. For example, an individual with arthritis (health condition) may experience weakness, stiffness, and a reduced range of motion (impairments).
- *Disability (activity limitations):* Difficulties an individual may have in executing a task or action. Examples include difficulty communicating, learning, performing tasks, or using standard computing technologies (e.g., keyboard, mouse). Disabilities are usually caused by impairments; an individual has a disability; disabilities are activity-specific. For example, a loss of muscle power in both arms (impairment) may interfere with an individual's ability to use a standard keyboard and mouse (disability).
- *Handicap (participation restrictions):* Problems an individual may experience in involvement in life situations. Handicaps can be caused by disabilities; an individual experiences a handicap; handicaps occur at a social level. For example, an individual may have difficulty communicating (disability) that places restrictions on the individual's ability to participate in educational and work activities, to participate in the exchange of information, and to maintain social relationships (handicaps).

Given these definitions, the distinction between a disability and a handicap is, in many ways, dependent on the individual. If an individual has an impairment (e.g., bending the fingers may be difficult) that makes it difficult to use a standard keyboard, then this individual has a disability with respect to the operation of this device. However, an individual only experiences a handicap if the inability to use the keyboard (e.g., disability) affects the individual's normal life activities. Our focus is on designing computing technology to lessen or even eliminate disabilities that may result from PI, the environment, or the context in which an individual is interacting with this technology. As a result, the potentially subtle differences between disabilities and handicaps are not important.

PHYSICAL IMPAIRMENTS AND COMPUTING

Impairments, as described by the WHO, can affect every structure and function of the body. As a result, there are impairments that interfere with the internal workings of the body as well as how we interact with our environment. In this chapter, we focus on the subset of PIs that are of particular interest when discussing the use of computers. More specifically, we focus on PIs that interfere with physical interactions with computing devices (e.g., interacting with a keyboard or mouse). Impairments, even PIs, that interfere with vision, hearing, and other activities involved in the use of computing devices are not discussed in this chapter (see chapters 24 and 26 for coverage of some of these issues). Four categories of PI are particularly relevant for the discussion that follows:

- *Structural deviations:* Situations in which there is significant deviation or loss with regard to anatomic parts of the body. Examples include the partial or total absence of a body part (e.g., missing finger, hand, arm) as well as situations in which a body part deviates from the norm in either position or dimension.
- *Mobility (of bone and joint) functions:* Mobility functions address an individual's ability to move a joint or bone. This includes both the range and ease of movement. For example, an individual may have limited range of motion or experience difficulty when bending his or her fingers (e.g., arthritis).
- *Muscle power functions:* Muscle power functions address an individual's ability to generate force by contracting a muscle or muscle group. Paresis (i.e., weakness) refers to the partial loss of power and can be caused by a variety of conditions (e.g., brain injury). Paralysis refers to the complete loss of power and can also be caused by various conditions (e.g., spinal cord injuries). Muscle tone and endurance functions may also be important in certain circumstances but tend to be less critical for most interactions with computing systems.
- *Movement functions:* Although additional movement functions exist, we focus on an individual's ability to control voluntary and involuntary movements. Difficulty controlling movements that involve a rapid change in direction (e.g., dysdiadochokinesia) would fit in the voluntary movement category. Uncontrolled shaking or trembling of the hands (e.g., essential tremors or tremors associated with Parkinson's disease) would fall under the involuntary movement category.

Although there are many other types of PI, including stability of the joints, motor reflex functions, and gait pattern functions, the four categories identified above account for the majority of PIs that hinder the use of computing technologies. As we discuss various health conditions, it is useful not only to identify specific PIs that may occur, but important characteristics of the PIs that may influence the design of alternative strategies or technologies. PIs can vary in many ways, but the following four dimensions are perhaps the most critical:

- PIs can be *permanent* or *temporary*.
- PIs may be *continuous* or *intermittent*. For example, individuals with multiple sclerosis experience relapses and remissions.
- PIs may be *progressive* (get more severe with time), *regressive* (get less severe with time), or *static* (no change with time).
- The severity of a PI can range from *mild* to *severe*. In other cases, severity is *variable*.

Temporary PI can be problematic because individuals may be hesitant to invest significant time or effort in adapting to new interaction techniques. If a PI is permanent, individuals will develop accommodation strategies, and learning new interaction techniques may be acceptable. Intermittent PI create difficulties because any alternative interaction technique that is provided must be accessible when needed without hindering interactions when the PI is not present. Progressive and regressive PIs require accommodations that can adapt as the impairment becomes more severe. Adaptation may be automatic or user-directed. When the severity of the PI is variable, the accommodation must also be able to adapt. However, the required adaptation can be more complex than that required for intermittent, progressive, and regressive PI because severity may increase or decrease at any given time, or the PI could completely disappear temporarily. PIs that are permanent, continuous, static, and of a fixed severity are perhaps the easiest to address. Under these conditions, the individuals are likely to adapt to their impairment, develop their own accommodation strategies, and be more willing to learn new interaction techniques. When PIs change with time (i.e., intermittent, progressive, regressive, or variable), providing effective solutions becomes more difficult.

HEALTH-CONDITION-INDUCED IMPAIRMENTS

It may be tempting to view all individuals with a particular PI as benefiting equally from a given accommodation. Unfortunately, this perspective can result in solutions that fail to adequately address the needs of the individual. Understanding the underlying health condition provides valuable insight into the nature of the associated PIs, which in turn provides insight into the characteristics of the accommodations that will prove beneficial.

We briefly describe some of the more common diseases, disorders, and injuries that result in PI that hinder the use of computing systems. For each health condition, the PIs that may result are identified and described. For additional information regarding any of the underlying health conditions, we refer the reader to the Merck Manual (Berkow, 1997) or the references included throughout the text that follows. Our descriptions assume that appropriate treatments (e.g., medication, surgery, therapy) have already taken place. Although we are not addressing the issues involved in perceptual, speech, or cognitive impairments in this chapter, we do highlight situations in which these impairments may be present. We do this for two reasons: to provide additional insights into difficulties individuals with specific health conditions may face (e.g., vision, hearing, or cognition difficulties). and to highlight situations in which specific alternative interaction strategies or technologies may not be appropriate (e.g., speech recognition).

Amyotrophic Lateral Sclerosis (ALS)

Amyotrophic lateral sclerosis (ALS) is also known as Lou Gehrig's disease (Taylor & Lieberman, 1988). ALS is a progressive disease that begins with weakness in the hands (less often, it begins in the feet). ALS progresses at a variable rate, but 50% of those affected die within 3 years of the initial symptoms, and only 10% live beyond 10 years. As the disease progresses, the weakness spreads to additional muscles and becomes more severe (eventually leading to paralysis that spreads throughout muscles of the body). With time, spasticity occurs resulting in muscles becoming tight. Spasms and tremors can also occur. ALS only affects those nerves that stimulate muscle action. Cognitive functions and sensation remain intact. ALS is characterized primarily by muscle power PI (weakness progressing to paralysis), but movement PI also occurs (stiff muscles, spasms, and tremors). The PIs are permanent, continuous, and progressive. Initially, they are mild, but with time they become severe. Note that with time the muscles involved in producing speech are affected.

Arthritis

Arthritis refers to the inflammation of a joint (Hicks, 1988; Schumacher, 1993). The two most common forms of arthritis are osteoarthritis and rheumatoid arthritis. Osteoarthritis (OA) is a chronic joint disorder that can cause joint pain and stiffness. It is characterized by degeneration of joint cartilage and adjacent bone, is the most common joint disorder, and is one of the most common causes of physical impairments (Berkow, 1997). OA is not an inevitable part of aging, but it does occur more often in the elderly. OA typically progresses slowly after symptoms first appear. OA can result in significant mobility PI (reduced range of motion, weakness, and difficulty with repetitive motions). The PIs tend to be permanent, intermittent or continuous, progressive, and can range from mild to severe.

Rheumatoid arthritis (RA) is an autoimmune disease that can cause swelling, pain, and often the eventual destruction of the joint's interior. RA is characterized by symmetric inflammation of the joints. RA typically appears first between 25 and 50 years of age, affecting 1% of the population. Most often, RA starts subtly, progressing at a highly variable rate. In some rare cases, RA spontaneously disappears and treatment is often successful, but RA can result in significant impairment of mobility (reduced range of motion, weakness, and difficulty with repetitive motions). The PIs tend to be permanent, continuous, and progressive. The severity of the PI is typically mild initially but in 10% of the cases will progress to severe.

Brain Injury

Brain injury (BI) is a term used to described a collection of injuries (Horn & Zasler, 1996; Rosenthal, Griffith, Bond, & Miller, 1990). Technically, there is a disconnect between the cause of the injury (e.g., penetration of the skull by a foreign object or the rapid acceleration or deceleration resulting from a forceful blow to the head or vehicular accident) and the injury itself. Common head injuries include skull fractures, cerebral contusions (bruises on the brain), cerebral lacerations (torn brain tissue), concussions (brief loss of consciousness after an injury), and intracranial hematomas (collection of blood in the brain or between the brain and skull). Head injuries are the most common cause of death and disability for individuals under 50 years of age. BI are not always the result of trauma. For example, anoxia can also result in BI. The consequences of a brain injury depend on the area of the brain affected and the severity of the injury. Possible consequences include death; language, vision, and motor control difficulties; and periodic headaches. As with a stroke, other parts of the brain can often assume the responsibilities of the damaged portion, lessening the severity of the resulting impairments. This ability is more prevalent in children, because their brains are more adept at shifting functions to different parts of the brain. The most common PIs are movement oriented (e.g., difficulty controlling muscles). After rehabilitation, the PI are considered permanent, continuous, and static. Severity may range from mild to severe.

Cerebral Palsy

Cerebral palsy (CP) is a condition that results from brain injury that typically occurs before, during, or shortly after birth. CP is not a disease and is not progressive (Molnar, 1992). Over 90% of those affected with CP survive to adulthood. There are four main types of CP: spastic, choreoathetoid, ataxic, and mixed. Spastic CP occurs in approximately 70% of those individuals with this condition and is characterized by both movement and muscle power PIs (stiff muscles and weakness). Choreoathetoid CP is characterized by movement PIs (spontaneous, slow, uncontrolled muscle movements; abrupt and jerky movements) and occurs in 20% of individuals with CP. Ataxic CP occurs in approximately 10% of those individuals with CP and is characterized by movement and muscle power PIs (poor coordination, weakness, trembling, difficulty with rapid or fine movements). Mixed CP occurs in many individuals and is characterized by a combination of two of the previously mentioned forms of CP. Seizures are also possible (most often with ataxic CP). In all four forms, the PIs are permanent, continuous, static, and may range from mild to severe. It is important to note that in all forms of CP, speech and intelligence can be affected.

Missing Limbs or Digits (Amelia or Amputation)

Technically, missing limbs or digits is an impairment, not a health condition (Banerjee, 1982). However, as with tremors, it is possible for limbs or digits to be missing without any associated health condition (e.g., congenital absence of a limb or digit is not considered a health condition). The PI associated with missing limbs or digits is permanent, continuous, static, and can vary from mild to severe depending on the use and effectiveness of a prosthetic device.

Multiple Sclerosis

Multiple sclerosis (MS) is a disorder in which the nerve fibers associated with the eye, brain, and spinal cord loose patches of myelin (a protective, insulating sheath; Adams & Victor, 1993). MS is progressive, but there is not single pattern that typifies its progression. It results in numerous symptoms, including a variety of movement and muscle power PIs (clumsiness, tremors, stiff muscles, weakness). It often results in periods of flare-ups, alternating with periods of relatively good health; in other individuals, the symptoms become more severe within weeks or months. As flare-ups become more frequent, the symptoms become more severe and may become permanent. The PIs are permanent, intermittent, and progressive; they may be mild initially but often progress to become severe. In addition to multiple PIs, MS can result in visual impairments.

Muscular Dystrophy

Muscular dystrophy (MD) is a group of inherited muscle disorders (Pidcock & Christensen, 1997). The two most common forms which only affect males, are Duchenne's MD (affecting 20 to 30 of every 100,000 boys) and Becker's MD (affecting 3 of every 100,000 boys). Duchenne's MD is more severe, appearing between the ages of 3 and 7; most children must use a wheelchair by 10 or 12, and death is common by age 20. Becker's MD is less severe, with symptoms appearing around age 10; few children are confined to a wheelchair by age 16, and more than 90% live beyond age 20. Both forms begin with muscle power PIs (weakness) that spreads and becomes more severe. This is often followed by mobility PI (joints that cannot be fully extended due to contracted muscles). Some PIs may not be present early (e.g., inability to fully extend the elbows). In both forms, the PIs are permanent, continuous, and progressive. Typically, the PIs are mild initially and progressively worsen.

Parkinson's Disease

Parkinson's disease (PD) is a degenerative disorder of the nervous system (Duvaisin, 1991). PD is characterized by degeneration of the nerve cells in the basal ganglia, which results in reduced production of dopamine (the main neurotransmitter of the basal ganglia). PD affects approximately 1 in 250 individuals over the age of 40 and 1 in 100 individuals over the age of 65. PD typically begins with mild symptoms and progresses gradually. It often begins with resting tremors (movement PIs). As the disease progresses, initiating a movement can become difficult, muscles become stiff, and bending the elbow can become difficult or uncomfortable (movement and mobility PI). The tremors vary dramatically. Some individuals never develop tremors. For others, they may be permanent or temporary; continuous or intermittent; progressive, regressive, or static; and can vary from mild to severe. Other PIs, including difficulty initiating movements and stiff muscles are permanent, continuous, and progressive. They are mild initially but progress to become severe. Still other PIs, such as difficulty bending the elbow, may never occur. Individuals with PD often speak softly in a monotone and may stutter.

Repetitive Stress Injury

Repetitive stress injuries (RSI) are known by a variety of names including cummulative trauma disorders and repetitive trauma syndromes (Moore & Garg, 1992). RSI refers to a collection of disorders or injuries that are believed to be associated with repetitive activities, but the precise cause is still a subject of debate. RSI are most commonly associated with the wrists but can affect other parts of the body. RSI most often result in mobility PIs (reduced range of motion, weakness, and difficulty with repetitive motions). The PIs are permanent, continuous or intermittent, progressive, and can vary from mild to severe.

Stroke

A stroke is defined as the death of brain tissue resulting from a lack of blood flow and insufficient oxygen to the brain (Wade, Langton Hewer, Skilbeck, & David, 1985). A stroke typically occurs when a blood vessel becomes blocked or bursts. The symptoms depend on the area of the brain that is affected but include vision, speech, cognitive, and physical impairments. Because other parts of the brain can assume the responsibilities of the damaged portion, it is possible to lessen the severity of the impairments that are apparent immediately following a stroke. Rehabilitation services are critical in this respect. The most common PIs are movement-oriented (e.g., difficulty controlling muscles). After rehabilitation, the PI can be defined as permanent, continuous, and static. The severity of the PI may be range from mild to severe.

Spinal Cord Injury

Spinal cord injuries (SCI) occur when the spinal cord (a collection of nerves extending from the base of the brain through the spinal column) is compressed, cut, damaged, or affected by disease (Stiens, Goldstein, Hammond, & Little, 1997). The spinal cord contains motor nerves (controlling movement) and sensory nerves (providing information about temperature, pain, position, and touch). The consequences of an SCI depend on the level and completeness of the injury.

The level of an injury is based on the nerves that are affected. The spinal column is divided into four areas: cervical (neck), thoracic (chest), lumbar (lower back), and sacral (tail bone). There are seven cervical vertebrae, numbered C1 through C7 from top to bottom. There are 12 vertebrae in the thoracic region (T1-T12), 5 in the lumbar region (L1-L5), and 5 in the sacral region. The level of an SCI refers to the location of the damaged nerves. In the cervical region, injuries are labeled based on the vertebrae immediately below the damaged nerves (e.g., level C1 refers to damage to the nerves just above vertebrae C1). Damage to nerves just below C7 and above T1 are referred to as level C8. In all other regions, injuries are labeled based on the vertebrae immediately above the damaged nerve (level T3 refers to injuries to the nerves between T3 and T4). In general, injuries higher on the spinal cord will result in greater impairment. Because PIs that affect the upper body have the most significant impact on the use of computing devices, Table 25.1 summarizes the possible consequences of high-level SCI.

The completeness of an injury is often assessed using a scale defined by the American Spinal Injury Association (ASIA, 2001). Although there are additional details and assessments must be completed by trained professionals, the following summaries provide sufficient detail for our purposes. Table 25.2 provides a brief description of the ASIA scores.

SCIs result in muscle power PIs. The level of the injury determines which muscles are affected. The completeness of the injury determines how much muscle power is lost. Injuries with ASIA scores of A or B result in a complete loss of muscle power (i.e., paralysis) in the affected muscles. Injuries that are classified as ASIA C or D are more difficult to describe because the amount of muscle power that remains can be highly variable (i.e., weakness or paresis). PI associated with SCI are considered permanent, continuous, and static, with the severity of the PI ranging from mild to severe depending on the completeness of the injury.

TABLE 25.1. Relationship Between the Level of a Spinal Cord Injury and the Resulting Effects on Muscles

Level of Injury	Effect
C1 to C5	Paralysis of muscles used for breathing, controlling the arms, and controlling the legs
C5 or C6	Paralysis of the legs; some ability to flex the arms remains
C6 or C7	Paralysis of the legs; paralysis of part of the wrists and hands; much of the ability to move the shoulders and to bend the elbows remains
C8 or T1	Legs and trunk paralyzed; hands paralyzed; arms remain relatively normal

Tremors

A tremor is an involuntary movement (Hallett, 1991). Tremors are produced by involuntary muscle activity and are often described as rhythmic shaking movements. Some tremors occur when muscles are in use (action tremors), whereas others occur when the muscles are resting (resting tremors). Intention tremors occur when an individual makes a purposeful motion.

TABLE 25.2. Residual Motor and Sensory Function Associated With Each American Spinal Injury Association (ASIA) Score

ASIA Score/ Completeness	Description of Motor and Sensory Function
A	Complete; no residual motor or sensory function below the level of the injury
B	Motor complete, sensory incomplete; there is no residual motor function, but some sensory capabilities remain in tact
C	Motor and sensory incomplete; most muscles below the level of injury are below three-fifths of normal strength
D	Motor and sensory incomplete; most muscles below the level of injury are at or above three-fifths of normal strength
E	Normal motor and sensory function

Tremors are a common consequence of various health conditions (e.g., MS or stroke). In these situations, the tremors are described under the appropriate health condition (e.g., see MS or stroke).

Essential tremors usually begin in early adulthood and slowly become more obvious (essential tremors that begin in the elderly are referred to as senile tremors). Essential tremors typically stop when the arms (or legs) are at rest, but become more obvious when the arms are held away from the body or in awkward positions. Essential tremors are relatively fast but result in little movement. The vocal cords can be affected by essential tremors, resulting in inconsistent speech. Essential tremors are permanent, intermittent, and can be progressive. Essential tremors are typically mild initially but may progress to be severe and can be variable. Essential tremors have no known cause, and for this reason we include tremors (which are technically a movement PI) in this list of health conditions.

Summary

Although the examples listed are some of the most common health conditions that result in PI, this is by no means a complete list. Table 25.3 summarizes the PIs that are frequently associated with each health condition, important characteristics of each PI, and any additional impairments that may be associated with the health condition that may influence the design of alternative strategies or technologies.

SITUATIONALLY-INDUCED IMPAIRMENTS AND DISABILITIES

As Fig. 25.1 indicates, both the environment in which an individual is working and the current context (e.g., the activities in which the person is engaged) can contribute to the existence of impairments, disabilities, and handicaps. Many environmental characteristics, including lighting, noise, vibration, and temperature, can affect an individual's ability to interact with computing technologies. Similarly, the context in which the activities are occurring can also hinder an individual's ability to interact with computing technologies. For example, the user may be engaged in other multiple activities that place demands on cognitive, perceptual, or physical capabilities (e.g., eyes-busy, hands-busy, or computationally intensive tasks). Stress can also affect an individual's ability to interact with computers.

In some of these situations, the environment or context creates temporary impairments. In other situations, there is no impairment, but a temporary disability does exist. For example, extended exposure to cold temperatures can make it difficult for an individual to bend one's fingers, creating a temporary mobility impairment (similar to arthritis). In contrast, an environment that is vibrating (e.g., a moving vehicle) does not alter any of the bodies structures or functions but can still make it difficult to use a stylus to enter text using gesture recognition. When the individual's physical capabilities are altered, the environment or context create a temporary PI. When the individual's physical capabilities are not altered but are instead rendered inadequate for the task the environment or context create a temporary disability. In both situations, the designer's goal is to minimize the negative impact of the environment and context on the computing activity.

Although extensive research has studied dual-task scenarios, in which participants were required to attend to two tasks at the same time, these studies tend to highlight decreases in cognitive performance rather than physical performance. At the same time, individuals are finding themselves in situations in which they are engaged in a secondary computing task with increasing frequency. For example, paramedics' hands may be busy providing medical care while they engage in a secondary computing activity to take notes and complete required forms. Extreme temperatures can affect both mental and physical activities with performance decreasing with extended exposure. An environment that is vibrating, such as a moving vehicle, can interfere with the performance of physical activities. Walking can also make more complex the physical activities required to interact with a mobile computing device.

Many factors, including temperature, movement, and multiple tasks, can adversely affect an individual's ability to perform the physical actions required to interact with computing technologies. Although some studies have been conducted (e.g., by the military), these relationships have yet to be systematically investigated and reported within the HCI literature. At the same time, the fundamental characteristics of these situationally-induced impairments and disabilities (SIID) are clear. Unlike impairments associated with health conditions that tend to be permanent, SIIDs are temporary. As a result, individuals experiencing them are less likely to develop their own accommodation strategies and are therefore more likely to benefit from technology-based accommodations. Because SIIDs are temporary, they are also intermittent. SIIDs may be progressive, regressive, or static depending on the conditions. Finally, SIIDs may range from mild to severe or could be variable. Effectively addressing the highly variable nature of SIID is an interesting and challenging area in need of additional research.

HCI RESEARCH AND PI

Researchers have approached the issue of designing computing technologies for individuals with PIs from a variety of perspectives. Many projects were clearly motivated by desire to address the needs of individuals with disabilities. A subset of these projects focuses on specific health conditions or PI. For example, researchers have investigated the development of a new interaction alternative for individuals with cerebral palsy (Roy, Panayi, Erenshteyn, Foulds, & Fawcus, 1994), cursor control for individuals with spinal cord injuries (Casali, 1992), and text entry for individuals with spinal cord injuries (Sears, Karat, Oseitutu, Karimullah, & Feng, 2001). Other projects are motivated by specific impairments or disabilities regardless of the underlying cause. For example, researchers have investigated the effect neck range of motion has on the use of head controls (LoPresti, Brienza, Angelo, Gilbertson, and Sakai, 2000) and the use of force feedback for individuals with various movement and muscle power PI that affect the hands (Keates, Langdon,

TABLE 25.3. Common Health Conditions That Can Result in Physical Impairments That Hinder Interactions With Standard Computing Technologies

Health Condition	Common PI and Characteristics	Additional Impairments
Amyotrophic lateral sclerosis (ALS) or Lou Gehrig's Disease	Muscle power: Weakness often begins in hands or feet. With time, loss of muscle power spreads and becomes more severe. Permanent, continuous, progressive, mild progressing to severe (paralysis).	In time, muscles throughout the body can be affected, including those involved in producing speech.
	Movement: Muscles can become stiff. Spasms and tremors can occur. Permanent, continuous, progressive, mild to severe.	
Arthritis	Osteoarthritis	
	Mobility: Reduced range of motion, weakness, difficulty with repetitive motions. Permanent, intermittent or continuous, progressive, mild to severe.	None.
	Rheumatoid arthritis	
	Mobility: Reduced range of motion, weakness, difficulty with repetitive motions. Permanent, continuous, progressive, mild to severe.	None.
Brain injury	Movement: A wide range of movement-oriented difficulties are possible depending on the location and severity of the injury. Permanent, continuous, static, mild to severe.	Speech, vision, and cognitive impairments are possible.
Cerebral palsy	Spastic	
	Muscle power: Weakness. Permanent, continuous, static, mild to severe. Paralysis does not occur.	Speech and intelligence can be affected.
	Movement: Stiff muscles. Permanent, continuous, static, mild to severe.	
	Choreoathetoid	
	Movement: Spontaneous, slow, uncontrolled muscle movements as well as jerky, abrupt movements. Permanent, continuous, static, mild to severe.	Speech and intelligence can be affected.
	Ataxic	
	Muscle power: Weakness. Permanent, continuous, static, mild to severe. Paralysis does not occur.	Speech and intelligence can be affected.
	Movement: Poor coordination, trembling, difficulty with rapid or fine movements. Permanent, continuous, static, mild to severe.	
	Mixed	
	Any combination of two forms listed above.	
Missing limbs or digits	Mobility. Permanent, continuous, static, mild to severe.	None.
Multiple sclerosis	Muscle power: Weakness. Permanent, intermittent, progressive, mild to severe. Paralysis does not occur.	Vision can be affected.
	Movement: Clumsiness, tremors, stiff muscles. Permanent, intermittent, progressive, mild to severe.	
Muscular dystrophy	Muscle power: Weakness that spreads and becomes more severe. Permanent, continuous, progressive, mild to severe. Paralysis does not occur.	None.
	Mobility: Joints that cannot be fully extended. Permanent, continuous, progressive, mild to severe.	
Parkinson's disease	Movement: Tremors (pill rolling) of one side are often the first sign. Permanent or temporary; continuous or intermittent; progressive, regressive, or static; mild to severe. Difficulty initiating movements and stiff muscles. Permanent, continuous, progressive, mild to severe.	Speech can be affected. Cognitive impairments are possible.
	Mobility: Difficulty bending the elbow. Permanent, continuous, progressive, nonexistent to severe.	
Repetitive stress injuries	Mobility: Reduced range of motion, weakness, difficulty with repetitive motions. Permanent, continuous or intermittent, progressive, mild to severe.	None.
Stroke	Movement: A wide range of movement-oriented difficulties are possible depending on the location (in the brain) and severity of the injury. Stroke does not always result in movement disorders. Permanent, continuous, static, mild to severe.	Speech, vision, and cognitive impairments are possible.
Spinal cord injuries	Muscle power: The specific muscles affected are determined by the level of the injury. How much power is lost is determined by the completeness of the injury. Permanent, continuous, static, mild to severe.	None.
Tremors	Movement: Tremors often affect the hands. Permanent, intermittent, progressive or static, mild to severe or variable.	Speech can be affected.

Clarkson, and Robinson, 2000). Both of these articles described studies that included individuals with a variety of underlying health conditions. Many articles that focus on the issues involved in addressing the needs of individuals with a specific health condition or PI are discussed below.

Another group of projects address issues associated with PI but do not identify any specific PI or health conditions as the motivation for the research. For example, several articles discuss communications issues for individuals "with severe speech and motor impairments" (e.g., McCoy, Demasco, Jones, Pennington, Vanderheyden, and Zickus, 1994), whereas others explore speech-based interfaces for "motor-control challenged computer users" (Manaris and Harkreader, 1998), new techniques for eye tracking that "could be useful to some people with physical disabilities" (Patmore and Knapp, 1998), and the use of word-prediction for text entry by "people with severe physical disabilities" (Garay-Vitoria and González-Abascal, 1997). Many articles that fit into this category are also discussed.

We have three goals for this literature review: (a) to summarize the current state of our knowledge with respect to designing computing technologies for individuals with PIs, (b) to highlight numerous unsolved problems in need of additional research, and (c) to provide pointers to numerous related articles that are not discussed. Although there are many ways to organize the articles we review, we choose to group articles by health condition or PI whenever possible. More focused articles are discussed first (e.g., articles that address specific health conditions or PI). Next, we present those articles that address less precisely defined PI (e.g., various impairments that affect the hands, regardless of the underlying health condition). The last set of articles have a clear association with PIs, but do not discuss any specific PI (e.g., articles that present a technology specifically in the context of individuals with PI but do not identify the PI or health condition). Occasionally, articles that may focus on a specific health condition are included in other sections because of the PI or technology discussed (e.g., Doherty, Cockton, Bloor, & Benigno, 2000). Throughout this section, we use terminology that is consistent with the definitions presented earlier. As a result, our terminology may differ from that used in the original articles.

Before discussing specific articles, we must acknowledge that there are several related bodies of literature that we do not discuss. First, we do not discuss the numerous articles that simply mention individuals with disabilities as one of the possible groups of users that may benefit from the results because this is beyond the scope of this chapter. For example, many articles discussing multimodal interfaces mention potential benefits for individuals with disabilities at some point, but few are designed specifically for this group of users (see chapter 14 for an introduction to multimodal interfaces and pointers to the relevant research). Second, we do not discuss those articles that focus on the more general problem of designing accessible computer systems without a significant focus specifically on PI. For articles of this nature, the reader is referred to the proceedings of the Association for Computing Machinery's ASSETS (2000) and Universal Usability (2000) conferences and the European Research Consortium for Informatics and Mathematics (2001) Workshops on User Interfaces for All. Stephanidis (2001) also discussed these issues. We encourage the reader to review this literature because it often provides valuable insights into the methods that can be used to more effectively integrate accessibility concerns into the overall development process. Finally, we do not discuss the extensive literature available in the rehabilitation and assistive technology communities. As with the literature that discusses accessibility from a more general perspective, we encourage the reader to explore the rehabilitation and assistive technology literature. More specifically, we refer the reader to the proceedings of the annual Closing the Gap conferences (Closing the Gap, 2001), Rehabilitation Engineering and Assistive Technology Society of North America conferences (RESNA, 2001), and the California State University—Northridge (2001) conferences. The *IEEE Transactions on Rehabilitation Engineering* often includes articles discussing the technical details of new devices and various books can provide valuable insights (e.g., Gray, Quatrano, and Liberman, 1998; King, 1999). Several books and Internet sites also can serve as useful starting points when exploring these issues (e.g., Edwards, 1995; Stephanidis, 2001; Trace Center, 2001).

Spinal Cord Injuries

SCI are one of the most frequently studied health conditions in the HCI community. Given the relationship between the level of injury and the resulting impairments, studies typically include individuals with injuries that are no lower than C7. The following articles discuss various topics including cursor control, validating keystroke-level models, a brain-controlled interface, and the use of speech recognition for communications-oriented activities.

Casali (1992) presented a study investigating the efficacy of five cursor control devices when used by individuals with SCI. Twenty individuals with SCI and 10 individuals with no PIs participated in this study. Participants with SCI were divided into two groups using a custom assessment test (see Casili, 1995; Casali & Chase, 1993) that evaluates upper extremity motor skills. As a result, three groups of participants were discussed: low motor skills, high motor skills, and participants with no PIs. Each participant used a trackball, mouse, tablet, and joystick in addition to the cursor keys to complete a series of tasks that required either selecting or dragging a target. Both target size and distance were varied systematically. Several configurations were made available for the mouse, tablet, and joystick to accommodate the abilities of the participants.

Numerous statistics are reported detailing significant differences due to group, device, target size, distance, and mode (selection vs. dragging). Numerous significant interactions were also identified. The reader is referred to the original article for the complete details, but several particularly interesting results are summarized here. First, participants in the low motor skill group took longer to complete the tasks than the individuals with no PI. In contrast, there was no significant difference between the participants in the high motor skill group and the participants with no PI. Second, the rank ordering of the devices (with respect to target acquisition time) was the same for all three groups. For all three groups, the mouse, trackball, and tablet resulted in the shortest task completion times, the cursor keys took longer, and the joystick was the slowest of the five devices. Third, target size becomes more important as motor skills decrease. Interestingly, the authors noted that all participants, even those in the low motor skill group, were able to complete the tasks with all five devices with minimal customization. However, they also noted that individuals in the low and high motor skills groups experienced substantial difficulty when using the mouse. More specifically, the majority of these individuals found holding the mouse button while moving the mouse (e.g., dragging an object) difficult and ended up relying on a toggle switch customization that was made available.

Koester and Levine (1994) investigated the ability of keystroke-level models to predict performance improvements that individuals with SCI would experience when using word-prediction software to enter text. Word-prediction software can reduce the number of keystrokes required to enter text but also increases the cognitive and perceptual demands placed on users. This tradeoff should prove useful for individuals with PIs, but empirical studies confirming these benefits are lacking. In this article, the authors described a study that provides insights into (a) the benefits word-prediction software can provide and (b) the effectiveness of keystroke-level models for predicting performance by individuals with PIs.

Eight individuals with no PIs participated in the study. All of these participants used a mouthstick to interact with the keyboard. None had previous experience with a mouthstick. Six individuals with high-level SCI also participated. These participants used their normal method of interacting with a keyboard (two used a mouthstick, four used hand splints). They completed the tasks with and without word prediction to allow performance improvements to be evaluated. Two interaction strategies were explored when using word prediction: (a) searching the list of possible words before every keystroke and (b) entering the first two letters and then searching the list of words before every subsequent keystroke. Possible keystroke savings ranged from approximately 21 to 41% for the first strategy and 15 to 30% for the second strategy, depending on the task. Finally, two models were explored: (a) a generic model based on parameters derived from the existing literature combined with new data from individuals with no PI and (b) a user-driven model based on parameters derived from the data collected in this study.

Extensive statistics are reported describing the accuracy of the generic and user-driven models for predicting differences in data-entry rates that would be observed as a result of the two interaction strategies. As may be expected, the user-driven models were more accurate than the generic models. User-driven models resulted in errors of approximately 6 percentage points across all participants, whereas the generic model resulted in errors of 53 and 11 percentage points for the participants with and without PIs, respectively. Clearly, using data that more accurately reflects the performance of the individuals being modeled results in more accurate models. For example, the user-driven models incorporated data that highlighted several important differences that were missed by the generic model: participants with PIs who were experienced with the input devices were faster at typing individual characters than the novice nonimpaired participants, actual keypress times are longer when using word prediction (especially for the participants with PIs), participants with PIs took longer to search the list of alternative words than nonimpaired participants. Perhaps more interesting than the model-accuracy results were the changes in data-entry rates observed for the two groups of participants. Overall, the models predicted modest improvements in performance (ranging from slight decreases to improvements of over 40%). Results for nonimpaired participants followed this same pattern, but the participants with PIs showed a consistent, and large, decrease in data-entry rates when using word prediction (ranging from approximately 20–50% reductions in data-entry rates). Also of interest are differences between the two groups of participants in terms of the effectiveness of the two interaction strategies used when using word prediction. Nonimpaired users were, on average, 4% slower with Strategy 2 (enter two characters, then search the word list), whereas users with PIs were almost 11% faster with Strategy 2.

Mason, Bozorgzadeh, and Birch (2000) described a brain-controlled switch that can be activated by imagining movement. Earlier articles described studies in which this technology was used by individuals with no PIs (Lisogurski & Birch, 1998; Bozorgzadeh, Birch, & Mason, 2000). These studies demonstrated that this technology could effectively identify both real and imagined finger movements. In this article, the authors described a study that involved two individuals with high-level SCI. Neither participant had any residual motor or sensory function in their hands. Their results indicated false-positive rates of less than 1% (i.e., the system detected activity when none was intended) and hit rates of 35 to 48% (i.e., the system detected activity when it was intended). Although higher hit rates are desirable, these results were viewed as positive because they confirmed that individuals with no residual motor or sensory function in their hands could activate the system by imagining finger movements. Furthermore, these results were obtained with relatively little training and technology that was not customized to the individual participants. As described later in Section 6.6, significant research is underway that explores the possibility of using electrophysiological data (as was done in this study) as input to computing systems.

Sears et al. (2001) discussed the results of an experiment designed to explore the effectiveness of speech recognition for communications-oriented activities when used by individuals with SCI as well as individuals with no PIs. The individuals with SCI all had injuries at or above C6 with ASIA scores of A or B, resulting in either no use or limited use of their arms and in their hands being paralyzed. After training and practice, participants completed several composition and transcription tasks. An analysis of data-entry rates, error rates, and the quality of the resulting documents provided interesting and encouraging results. Overall, there were no significant differences between the two groups of users. On average, the participants generated text at approximately 13 words per minute (wpm) with few errors. An analysis of subjective satisfaction ratings revealed several differences, with the participants with PIs exhibiting significantly more positive attitudes with respect to the time required, the effort involved in correcting errors, and the overall ease of use of the software. A more detailed analysis revealed significant differences with respect to the processes employed by the two groups of participants. For example, the participants with PIs spent more of their time dictating and interrupted their dictation more often to correct errors. As a result, they also spent less of their time navigating from one location to another within the document. Oseitutu, Feng, Sears, and Karat (2001) provided additional details that highlight the different strategies adopted by these two groups of participants.

Cerebral Palsy

CP can result in a variety of impairments due to reduced muscle power or a loss of control over voluntary or involuntary movements. In addition, CP can result in both impaired speech and intelligence. As a result, designing technologies for individuals with CP can be particularly challenging. In this section, we discuss the results of a single study that was motivated explicitly by CP. Additional studies discussed later (see Cursor-Control Technologies) may have been motivated by CP. For example, Alm, Todman, Elder, and Newell (1993) describe a system designed for individuals with severe speech and motor impairments including an evaluation that included one individual with CP.

Roy, Panayi, Erenshteyn, Foulds, and Fawcus (1994) discussed the design of a gestural interface designed for individuals with speech and motor impairments due to CP. Fourteen students with CP, aged 5 to 17, were observed during their regular school schedules. They observed numerous communicative acts that combined facial expressions, eye gaze, vocalization, dysarthcic speech (slurred, slow, difficult to produce, and difficult to understand), and upper extremity gestures using the head, arms, hands, and upper torso. Subsequently, four students participated in sessions in which data were collected for a predefined set of gestures (using a three-dimensional magnetic tracker and electromyographic electrodes). Computer recognition was tested for two similar gestures, providing encouraging recognition rates of approximately 96% and 93%. An evaluation of the complete set of gestures, or the subsequent use of such gestures by individuals with CP, was not reported in this article; however, the preliminary data provides encouragement with respect to the use of computer-based gesture recognition as a communications tool for individuals with CP.

Impairments of the Hands and Arms

Several studies have focused on the difficulties individuals experience because of movement or muscle power PIs that affect their hands and arms. These studies often include participants with a range of underlying health conditions (e.g., CP, SCI, stroke) as well as varying PIs. The unifying theme for these studies is that they all focus on the ability of the study participants to interact with computers using the arms and hands.

Trewin and Pain (1999) discussed the errors that occur when individuals with PI that affect their hands and arms interact with a keyboard and mouse. The authors began by acknowledging the difficulties individuals with PIs may experience using a keyboard and mouse but proceeded to highlight the lack of empirical data regarding the nature and frequency of these difficulties. Twenty individuals with various PIs and six individuals with no PIs participated in this study. The difficulties each individual experiences are associated with either a health condition (e.g., stroke, CP, spina bifida) or a PI (e.g., wrist stiffness, coordination loss, spasms), and the method each individual normally used to type was listed (e.g., right hand only, several fingers on both hands, thumb and first two fingers of left hand). Each participant completed three tasks: one used the keyboard, one used the mouse, and one used both the keyboard and mouse. Several important categories of typing errors were identified, with each type of error occurring more often for the participants with PI. The following six categories account for the majority of performance errors (in decreasing order of frequency):

- *Long key presses:* A key was pressed longer than the default key repeat delay and would have resulted in multiple characters being entered if the default delay were used. Participants with PIs pressed keys longer and the duration of keypresses was more variable. This was the most common problem, with 2,610 keypresses lasting longer than the default key repeat delay; however, this does not represent the number of keypresses that resulted in multiple keys because key repeat was disabled for many users and the key repeat delay was extended for the remaining participants.
- *Additional keys (local):* These are errors where a key near the desired key was accidentally activated by the body part being used to type. Of the 265 errors that fall in this category, almost 98% involved an adjacent key being pressed.
- *Missing keys:* A movement intended to generate a character failed. This could be because some other key was pressed (additional key error) or because insufficient force was applied to the key. This error occurred 179 times.
- *Simultaneous keys:* The participant failed to press two keys simultaneously when necessary (e.g., using the shift key). Participants with PI found it difficult to press two keys simultaneously, resulting in 56 errors. Nine participants used the caps-lock key as an alternative to pressing two keys simultaneously, and one participant simply omitted capital letters and punctuation. Another participant indicated that he normally avoided capital letters unless absolutely necessary, but did enter them during this study.
- *Bounces:* A key was accidentally pressed more than one time. Forty-four bounce errors occurred, but reasons for these errors are not identified.
- *Additional keys (remote):* These are errors in which a key that was not near the desired key was accidentally activated by a body part that was not being used to type. Thirty-seven instances of remote additional key presses were identified. Most often this involved pressing an extra key on the bottom row of the keyboard.

Several interesting results were also reported with regard to the mouse-based tasks:

- *Pointing:* Simply pointing at targets was difficult. Participants with PIs took almost 3 times longer than those with no PIs when pointing at targets of various sizes. Although participants with no PI did not make any pointing errors, those participants with PIs made many errors. Seventy percent of the participants with PIs had error rates greater than 10%, and 40% of the participants had error rates in excess of 20%.
- *Clicking on a target:* The mouse down and mouse up positions were not identical for only 6% of the mouse clicks by the participants with no. More than 28% of the mouse clicks by participants with PIs involved some kind of movement.
- *Attempts to click the mouse button more than one time:* Participants with PIs failed at this task more than 39% of the time, whereas those participants with no PIs failed 9% of the time. Interestingly, the reasons for the failures differed between the two groups of users. For participants with no PIs, most failures (66%) were caused by clicking the wrong number of times, with the remainder (33%) resulting from missing the target. In contrast, for participants with PI, 33% occurred when the participant moved the mouse during the clicks, 27% resulted from missing the target, 25% involved the wrong number of clicks, and 14% happened because the user clicked too slowly.
- Participants with PIs took longer to complete dragging tasks than participants with no PIs. Participants with no PIs experienced a failure rate of 5%, with all failures occurring because they missed the target. Participants with PIs were more error prone, with 55% of their attempts failing; 40% of the failures involved missing the target when releasing the mouse button, and almost 34% involved releasing the mouse button accidentally while dragging the object, 14% involved getting stuck (e.g., moving the mouse to a location where they were no longer physically capable of completing the dragging task) and having to give up, and 11% involved situations in which the user accidentally caused the window to scroll by dragging the object out of the current window.

The difficulties identified in this study provide valuable insights into the experiences of individuals with PIs. Numerous additional details are provided in the original article that could guide future research aimed at making the standard keyboard and mouse more effective for individuals with PIs. For additional related work, see Trewin (1996) and Trewin and Pain (1998a, 1998b).

Keates et al. (2000) discussed the use of haptic feedback for individuals with PIs. More specifically, they investigated the potential of force feedback to facilitate point-and-click activities. They report on two pilot studies that focus on individuals with movement and muscle power PIs but unaffected sensitivity of touch. Six individuals with various health conditions that result in PIs participated in the studies. Four participants had choreoathetoid CP, one had Friedrich's ataxia, and one had Kalman-Lamming's syndrome. Participants completed a series of point-and-click activities. In the first study, the efficacy of several alternative forms of feedback were explored: a pointer trail, changing the color of the target when the cursor is over it, force feedback gravity wells that draw the cursor toward targets, vibrating the mouse when the cursor is over the target, or a combination of all of these forms of feedback. Their results indicated that gravity may reduce target selection times by 10 to 20%. Similar benefits were also seen for pointer trails, a standard accessibility option in the Windows operating systems. Vibrating the cursor increased target selection times dramatically, with all participants expressing a dislike for this form of feedback. Interesting, these results are similar to those reported for participants with no PIs using the Phantom input device (Oakley, McGee, Brewster, & Gray, 2000).

In Keates et al.'s (2000) second study, the relationship between force feedback and target size was explored. Force feedback reduced the time required to complete the target selection tasks by 30 to 50% and error rates by approximately 80%. Without force feedback the time required increased as target size decreased. This pattern was greatly reduced when force feedback was provided. Interestingly, at least one participant was unable to complete the tasks without force feedback but could perform the required activities when force feedback was provided. These results suggest that force feedback could prove useful for individuals with PI. It should be noted, however, that these results may be unique to the specific form of force feedback used in this study. Careful evaluation of other forms of force feedback is still necessary.

Keates, Clarkson, and Robinson (2000) discussed the use of existing user models for describing the behavior of computer users with PI. The concern is that these models tend to be calibrated based on performance of computer users with no PIs. The article investigates the use of the model human processor (Card, Moran, & Newell, 1983) for describing the behavior of computer users with PIs. This model combines perceptual, cognitive, and motor activities to predict the time required to complete a task. Tasks were developed to allow the time required for fundamental perceptual, cognitive, and motor activities to be determined for two groups of users. The first group consisted of six individuals with PIs caused by various health conditions (i.e., quadraplegia, MD, spastic CP, choreoathetoid CP, and Friedrich's ataxia). A second group of three individuals with no PI also participated. Their results are summarized in Table 25.4.

Participants with PIs appear to take longer to complete fundamental perceptual and cognitive activities. These results are consistent with those discussed above (Koester & Levine, 1994) but should be interpreted carefully given varied health conditions of the participants. In particular, the fact that individuals with CP participated and that CP can affect more than just physical activities suggests that a more detailed review of the results is necessary. Fortunately, the authors provided the results for

TABLE 25.4. Average Time Required by Individuals With and Without Physical Impairments (PIs) to Complete Fundamental Perceptual, Cognitive, and Motor Tasks

	Perceptual	Cognitive	Motor
No PI	80 ms	93 ms	70 ms
PI	100 ms	110 ms	110 ms, 210 ms, 300 ms

each participant, and a careful review suggests that the additional time required for perceptual and cognitive activities is not due to the participation of individuals with CP. Less surprising is the additional time required for motor activities. It is also not surprising that the time required by participants with PI varied dramatically, with the two slowest participants requiring almost 3 times as long as the two fastest participants. These results confirm the need to develop user models that are specific to the individuals who may use the system.

Through observation and an analysis of the different times recorded for motor activities, the authors concluded that additional cognitive or perceptual activities are taking place when individuals with PIs complete basic motor tasks (as compared with individuals with no PIs). Based on additional data, the authors suggested that additional cognitive activities are the likely explanation. Although their results are not definitive, they confirm the need for additional research that focuses on the time required to complete basic perceptual or cognitive activities. These results also demonstrate the need to study the activities that occur when individuals with PIs perform basic motor activities.

Impairments in Infants

Infants with severe PIs often develop to be passive, with limited or nonexistent speech. This is true even when cognitive skills are normal. Fell, Delta, Peterson, Ferrier, Mooraj, and Valleau (1994) discussed the development and evaluation of the Baby-Babble-Blanket as a technology to enable infants with severe PIs to control their environment and communicate. One goal was for this technology to help these infants improve their motor skills. The key component of the system is a pad, containing 12 equally spaced switches, that can be placed on the floor. When a switch is pressed, a computer provides feedback. The feedback varies but can include digitized speech, music, and sounds. The authors reported the results of a single-subject experiment involving a 5-month-old infant with poor muscle tone, hydrocephaly, and club feet. This infant was able to activate switches, became more active when sounds were played in response to switch activations, associated switches with a desired effect (i.e., hearing his mother's voice), and was able to modify these associations when the feedback was moved from one switch to another.

Significant Speech and Physical Impairments (SSPI)

Although the terminology may vary, several studies discuss technologies for individuals with significant speech and physical impairments. The article by Roy et al. (1994) discussed earlier could have been included here but was listed separately because of its explicit focus on impairments caused by CP. Of the three articles summarized below, one presents the results of an evaluation including a single participant with CP, whereas the other two discuss technologies without explicitly mentioning any health conditions. An individual's ability to speak can be impaired when PIs affect the muscles involved in producing speech or when the cognitive processes involved in producing speech are impaired.

Alm et al. (1993) described the development of a computer-aided communication technology for individuals with SSPI. This article focuses on situations in which the speech impairment results from physical rather than cognitive impairments. Under these conditions, the individual can understand incoming communications but has difficulty expressing thoughts. Although most existing systems store words (and require the user to construct sentences) or a limited number of prerecorded phrases or sentences, the authors described a system that tracks the conversation and helps the user select the next thing to say. The system allows users to specify the type of utterance they wish to generate using a limited number of parameters. For instance, the user can select greetings or wrap-up comments. In a prototype system designed to support conversations about vacations, the user specified the person (i.e., me or you), time (i.e., past, present, future), and topic (e.g., who, where, when), and a set of possible utterances were displayed.

The system was evaluated with two participants. The evaluation system was loaded with 1,600 utterances developed to support conversations about vacations. For comparison purposes, three person-to-person conversations were recorded. The mean rate of speech was 144.4 wpm. One participant with no PIs took part in eight conversations with student volunteers. The mean rate of speech was 88.2 wpm. The participant speaking with the assistance of the computer spoke 67.4 wpm, whereas the conversation partners spoke 132.9 wpm. Although selecting an utterance could require one to four clicks, only 2 of 422 selections actually involved more than two clicks. This suggests that the desired utterances were easily accessed given the current design of the system. Informal evaluations of the conversations yielded positive results, suggesting that further study is appropriate.

The second participant had CP. His primary method for communicating was a word board with 400 words that he could point to. He augmented this with some gestures, limited vocalizations, and a word and phrase storage device that could be used for names of people, places, and other special words. Because of his difficulties reading, the interface was simplified by reducing the number of text windows and reducing the options available to change perspectives (e.g., person, time, topic). The system was used to augment his normal communication techniques. The results indicate that the system allowed the participant to express himself more fully, increasing his vocabulary from 143 to 534 words and the number of times he took control of the conversations from 10 to 27.

Many important questions must still be addressed for systems such as the one described in this article. One critical issue is the effectiveness of such a system as the number of conversation topics increases. As more topics are discussed, the number of phrases increases, and the task of managing this information will become more complex. Another critical issue is how the user can efficiently enter and organize these phrases as they customize the system for use in new situations.

Demasco, Newell, and Arnott (1994) discussed the development of system to support communications activities that is based on principles of visual information seeking. Building on five key principles derived from the literature, a computerized word board application was designed. Key features include the separation of navigation and selection, which allows these activities to be supported by different devices and expanding the collection of words that are accessible using word associations (e.g., is-like, is-a, has-a, goes-with). At the time the article was written, the system was under development and a variety of directions for research were presented. The authors also provide an interesting discussion of the limitations of existing computer-based communications systems, including those that use word prediction, coding systems, and level-based systems.

Albacete, Chang, Polese, and Baker (1994) also discussed the design of iconic languages for use by individuals with SSPI. This approach is based on semantic compaction in which ambiguous icons are combined to represent concepts. For example, "APPLE VERB" could mean *eat* while "APPLE NOUN" means *food*. An icon algebra is defined, including operators to combine, mark, provide context for, enhance, or invert icons. The approach described in this system can allow a vocabulary of several thousand words to be represented with 50 to 120 icons. This approach served as the foundation for the Minspeak system.

Input Using Electrophysiological Data

Traditional input techniques involved some kind of physical activity. Most often, the hands and arms are involved, but other technologies allow users to provide input by moving their eyes, heads, tongue, or eyelids (see Cursor-Control Technologies). Recently, a number of researchers have been investigating input techniques that do not require physical activities. The article by Mason et al. (2000) discussed earlier provides one example in which electrophysiological data were used to generate input to a computer. In this section, several additional articles that discuss the use of electrophysiological data are discussed. This is a new, exciting, and promising form of input for individuals with significant PI.

Patmore and Knapp (1998) discussed a new approach to eye tracking that uses the electrooculogram (EOG) and visual evoked potentials (VEP) as input. Although a number of EOG-based eye-tracking systems have been discussed, additional research is needed to make such systems reliable (see LaCourse & Hludik, 1990; Patmore & Knapp, 1995). The VEP is a response to a flash of light that is highly sensitive to the stimulus' distance from the center of the field of vision. The authors presented the technical details of system that combines the EOG, the VEP, and fuzzy-logic to improve accuracy. Although promising, significant additional research is necessary before such a system will be sufficiently reliable for use under realistic conditions.

Allanson, Rodden, and Mariani (1999) described a toolkit designed to explore the use of electrophysiological data in interactions with computers. They discussed the variety of electrophysiological data available including the electroencephalograph (EEG), electromyograph (EMG), and galvanic skin resistance (GSR). The EEG is an electrical trace of brain activity, the EMG can detect the state (i.e., complete relaxation, partial contraction, complete contraction) of a muscle, and the GSR measures changes in the resistance of the skin. The authors provided several interesting references describing the use of the EEG to turn switches on and off (Kirkup, Searle, Craig, McIsaac, and Moses, 1997) and differentiated between five tasks (Keirn & Aunon, 1990) and the EMG to control computer games (Bowman, 1997) or manipulate objects on a computer (Lusted & Knapp, 1996). Their toolkit integrates these signals using predefined widgets that allow the signals to be used to drive applications.

Kübler et al. (1999) discussed the use of slow cortical potentials in a 2-s rhythm to control cursor movements on a computer screen. Three individuals with advanced ALS participated in extensive practice sessions to learn to control this signal. Ultimately, two of the three reached accuracy rates between 70 and 80%, which allowed these individuals to select letters and words displayed on a computer screen.

Doherty et al. (2000) discussed the use of formative experiments and contextual design to assess the potential of applications controlled by eye movements, the EOG signal, and the EEG signal (i.e., the Cyberlink interface). An initial study involving 44 participants with various PIs demonstrated some expected limitations (e.g., the mouse was not effective when arm and hand control was limited; eye tracking was not effective when peripheral vision was impaired) as well as unexpected difficulties (e.g., some quadriplegic participants could not produce signals below the neck and therefore could not operate the GSR device). Interestingly, the Cyberlink interface was the only alternative that all 44 participants could use to navigate a maze. Additional studies were used to address several practical and technical issues identified in the earlier phases of the project. Overall, their results confirm that interfaces built upon electrophysiological data can be useful for individuals with PI but that substantial additional research is necessary before the full potential of these technologies will be realized.

Kennedy, Bakay, Moore, Adams, and Goldwaithe (2000) discussed an experimental interface that requires the implantation of special electrodes into specific areas of the brain. At present, three individuals have had the electrode implanted. The first individual died from her underlying disease, and the third had had the surgery too recently to provide useful results. Therefore, results from the second individual are described. For this individual, EMG signals from various muscles are used to supplement the neural signals detected by the electrode. With 5 months of practice, the individual learned to control cursor movements. Results for three tasks are reported. These tasks involved moving the cursor across the screen, placing the cursor on an icon or button, and selecting the icon or button by holding the cursor still for a predefined period of time (or activating a predefined EMG signal). Through these tasks, this individual was able to invoke synthesized speech for predefined messages, spell names, and answer questions. As with the other articles summarized in this section, this article demonstrates the potential of electrophysiological data while confirming the need for additional research.

Cursor-Control Technologies

Cursor control and text generation are perhaps the two most common activities when interacting with computers. In fact, cursor control can form the foundation for text generation and therefore may be the most fundamental task in which individuals with PIs engage. Numerous technologies have been explored for controlling the location of the cursor on a computer screen and many of the articles summarized earlier focus on cursor control tasks. Although new eye-tracking technologies are being explored, commercial systems are readily available and can prove useful for individuals with PI. The issues involved in using these technologies are not discussed in this chapter, but Sibert and Jacob (2000) provided useful pointers to the recent literature on this topic. In the following sections, technologies are discussed that allow individuals to control the cursor using their head, tongue, eyelids, or speech.

Head. For individuals who have limited use of their hands and arms, other options must be found for interacting with computers. One option is to control the cursor location using head movements. In this section, we discuss several articles that explore the issues involved in interacting with computers via head movements.

Radwin, Vanderheiden, and Lin (1990) discussed the results of a study comparing a standard mouse to a lightweight ultrasonic head-controlled pointing device. Ten participants with no PIs completed a variety of tasks that required the selection of circular targets. The size of the targets and the distance to the targets were systematically varied. Radwin et al. reported movement times, cursor path distance, and deviation of the cursor from the optimal path. Distance, target size, and device all significantly affected movement times. Interestingly, target size had a greater effect for the head-controlled device, with movement times decreasing more dramatically than when the mouse was used. For example, moving from the small to medium sized targets reduced movement times by 249 ms when using the mouse and 525 ms when using the head-controlled device. The direction of the movement also affected movement times, with the horizontal movements resulting in the shortest times for the mouse and vertical movements resulting in the shortest times for the head-controlled device. Interesting results are also reported for the cursor path distance and amount the cursor deviated from the optimal path when the head-controlled device was used: Vertical and horizontal movements resulted in shorter paths and smaller errors than diagonal movements.

Results are also reported for two individuals with CP with details provided for one of these individuals. The results for this individual highlight the importance of carefully assessing the abilities of individuals with PI when designing computer systems for their use. For participants with no PI, vertical and horizontal movements were the most efficient with diagonal movements creating more difficulty. For this participant with CP, movements to the right resulted in more difficulty than any other direction. Interestingly, providing torso support allowed this individual to complete the tasks more efficiently, with the greatest improvement being for those tasks that involved moving to the right.

Lin, Radwin, and Vanderheiden (1992) reported on a similar study that focused on the relationship between control-display gain and performance with both mouse and head-controlled device. Ten participants with no PIs participated in this study. Movement times and deviation of the cursor from the optimal path were reported. Extensive analyses of the results are provided, highlighting the importance of target size, movement distance, and gain. Gain had an effect on movement times, but this effect was smaller than that of target size and movement distance. A U-shaped curve was observed for both the mouse and head-controlled device. The optimal mouse gain was between 1.0 and 2.0, whereas the optimal gain for the head-controlled device was between 0.3 and 0.6. The reader is referred to the original article, as well as to Schaab, Radwin, Vanderheiden, and Hansen (1996), for additional information regarding the relationship between control-display gain and performance with head-controlled devices.

Malkewitz (1998) described a system that combines head movements to the control cursor location with speech to click the mouse buttons, activate hotkeys, and emulate the keyboard. The goal was to provide access to standard applications by emulating standard input devices (i.e., keyboard and mouse). Speech recognition is restricted to a predefined set of commands and the ability to enter individual letters. Full dictation is not supported for various reasons. Although preliminary results were encouraging, the authors noted the need for additional research.

Evans, Drew, and Blenkhorn (2000) described the design of a head-operated joystick. Unlike many other projects that investigated the use of head-controlled devices that effectively emulate a mouse, this article explores a device that emulates a joystick. Also unlike most of the articles summarized in this chapter, this article focuses on the technical details of the device and provides little information about its use. The authors briefly summarize the results of an evaluation involving 40 participants (9 with undocumented impairments). It is reported that all 40 individuals used the device successfully, but detailed measures were not provided. The nine individuals with impairments used not only this device, but also a commercially available device that emulated a mouse. Interestingly, all nine preferred the joystick emulation provided by this new device over the mouse emulation provided by the commercial device. It is speculated that this preference is due, at least in part, to the fact that users can rest their head in a neutral position once the cursor is placed in the correct location when using a device that emulates a joystick.

LoPresti et al. (2000) conducted a study that investigated the relationship between neck range of motion and the use of head-controlled pointing devices. Fifteen individuals with no PIs participated in the study. Ten individuals with various health conditions that resulted in PIs affecting neck movements also participated. The individuals with no PIs were confirmed to have greater neck range of motion than those participants with PIs. All participants completed both target tracking and icon selection tasks. A head-mounted display was used as opposed to a traditional desktop monitor. The results confirmed that the individuals with PI were less accurate and took longer when completing the icon selection tasks. They were also less accurate when performing the target tracking task. Furthermore, their performance was much more variable than that of the participants with no PIs. As with several other studies, the authors found that models developed based on individuals with no PIs do not accurately represent the performance of individuals with PIs. A more detailed review of the results indicated that vertical movements were faster than horizontal movements and that horizontal movements were faster than diagonal movements. LoPresti (2001) reported similar results.

Tongue. Salem and Zhai (1997) provided a brief description of a system that allows the cursor location to be controlled using a tongue-operated isometric joystick like those available on many portable computers. A Trackpoint joystick was mounted in a mouthpiece, similar to those used by athletes that is fitted to the individual's upper teeth. Two individuals participated in a pilot study. Neither had experience with an isometric pointing device. Both used the tongue-controlled joystick as well as a standard finger-controlled joystick. Participants completed multiple trials involving 15 tasks. For each task, participants selected 1 of 20 buttons as quickly as possible. Initial performance was substantially better when using their fingers, but with practice the gap between the two devices narrowed. During the last trial, the tongue-based device was 5% slower than the finger-based device for one participant and 57% slower for the other. The authors suggested that with additional research performance with the tongue-based joystick could improve further.

Eye Lid. Shaw, Loomis, and Crisman (1995) presented a system designed to allow individuals to control various devices, including computers, by opening and closing their eyes. Both eyes are monitored and the duration of each eye closure is identified as blink, short, long, or super long. Audio feedback is provided to help users with timing their input. The application described in this article is the control of a powered wheelchair, but this technology could also be used to interact directly with computers. In fact, computer control is demonstrated through a simulation program that users interact with before controlling a wheelchair. Two individuals used the system. The first (Participant A) had a high-level SCI resulting in no residual use of his arms or hands. The second (Participant B) had a stroke and could only control a single eyelid. With 6 hours of practice, Participant A was able to move from interacting with the simulation software to using the powered wheelchair. He found this device to be less obtrusive than the chin control he normally used to control his wheelchair. After 12 hours of practice, Participant B was able to navigate the maze presented by the simulation software and made progress toward controlling the powered wheelchair. Given the minimal motor control this individual exhibited, this is a noteworthy accomplishment.

Speech. Manaris and Harkreader (1998) investigated a speech-based interface for accessing all of the functionality provided by a computer. Their system, SUITEKeys, allows users to access the functionality of a standard keyboard and mouse using speech recognition. Users can access the keyboard by saying *press <key name>*, *release <keyname>*, or simply *<key name>* to initiate a complete keystroke. Saying *repeat <key name> <number of repetitions>* produces multiple keystrokes. The cursor can be moved by saying *move <direction>* to move at a slow speed until another command is issued, *stop* to stop the cursor where it is, *move <direction> <distance>* to move a specified distance, or *position <area>* to move the cursor to the center of five predefined regions of the screen. Clicking mouse buttons can be accomplished by saying *press <button name>*, *release <button name>*, *click <button name>*, or *double-click <button name>*. A pilot study involving three participants with PI that interfered with the use of a standard keyboard and mouse is described. Each participant completed a data-entry task using their normal input technique (i.e., a keyboard and mouse, directing an assistant to perform the necessary actions, using the keyboard via a mouthstick) and using SUITEKeys. The results indicate that even with minimal practice, these three individuals were able to achieve reasonable data-entry and accuracy rates with the SUITEKeys system. Additional study is required to evaluate the effectiveness of this system with additional practice.

Text Entry Technologies

Computers are frequently used to generate text. Although the keyboard is the most frequently used alternative, other technologies can also be used to generate text. Some individuals with PI select letters from on-screen keyboards, others use speech recognition, and still others interact with the standard keyboard. When using an on-screen keyboard, text entry is effectively turned into a cursor-control task. As a result, all of the cursor-control technologies discussed earlier can also be used for text entry. The article by Sears et al. (2001) discussed the use of speech recognition for text entry, but was included in the section on spinal cord injuries because of its primary focus. All three articles in the section on SSPI could be included here but are discussed separately because of their focus on individuals with a specific collection of impairments. The articles included below discuss technologies that can be used for text entry without focusing on any health condition or PI.

Keyboard-Based Text Entry. Matias, MacKenzie, and Buxton (1993) described a one-handed keyboard based on the traditional QWERTY design. The basic design allows users to access all of the keys on one side of the keyboard at a time, switching between sides by pressing and holding the spacebar. A study with 10 participants with no PIs is reported. Each participant used their nondominant hand when typing with one hand. Participants completed 10 sessions, with no more than one session per day. Each session included a two-handed pretest, several blocks of one-handed typing, and a two-handed posttest. Speed and errors improved significantly over the 10 sessions. By the end of 10 sessions, participants were typing 34.7 wpm with an error rate of 7.44% with the one-handed keyboard compared with 64.9 wpm and 4.20% errors with the two-handed keyboard. This design was intended to leverage existing knowledge and skill associated with the QWERTY keyboard. While this system could prove useful for individuals with PIs that hinder the use of one hand, the efficacy of this design for individuals with limited experience using the QWERTY keyboard is uncertain.

Many researchers have investigated techniques that allow users to generate text using fewer keystrokes than is normally required. These techniques typically predict words given just a couple of letters using statistics that describe how frequently various words are used. Some systems also use statistics regarding how frequently various words follow words that have already been entered. Other techniques present multilevel interfaces where users repeatedly select categories until the desired word is available. Once the word is selected, an appropriate ending (e.g., "s" or "ing") can be added. Demasco and McCoy (1992) presented a theoretical discussion of a word-based virtual keyboard that uses a level-based interface. McCoy et al. (1994) discussed a word-based text entry technique in which users specify uninflected content words and the system adds appropriate endings to the words as well as additional words (e.g., articles, prepositions) to complete the sentence. Garay-Vitoria and González-Abascal (1997) discussed the potential of syntactic analysis of previously entered words to enhance word-prediction results. Boissiere and Dours (2000) described a system that predicts word endings without assistance from the user. Unlike many of the articles discussed earlier, these take either a theoretical or systems approach to the problem. Consequently, some of the systems have not been implemented. Systems that are implemented are described, but user-based evaluations are not reported.

Speech Recognition-based Text Entry. Goette (1998) conducted a field study to identify factors that influence the successful adoption of speech-recognition software for both dictation-oriented and environmental control tasks. Individuals with various health conditions (e.g., MS, MD, SP, arthritis) participated. Most individuals who stopped using the speech-recognition software (53%) did so within 3 months. Interestingly, those individuals who successfully adopted the software had higher expectations for the system and expected greater benefits but also believed the system would be easy to use compared with those individuals who stopped using the software. When SR was successfully adopted, it was used for a wide variety of computer-based tasks rather than a few isolated activities. Four guidelines were proposed for successful outcomes: managing expectations by understanding the potential benefits and limitations, selecting the correct system for the tasks to be accomplished, obtaining thorough training, and trying the system for an extended period of time before purchasing it.

CONCLUSIONS

The most obvious conclusion is that additional research in designing computer technologies for people with physical impairments is necessary. PIs vary dramatically in terms of severity, temporal variability, and the body parts that are affected. Numerous technologies can be used in a variety of configurations. Given this variability and the limited number of studies reported in the literature, it is clear that only a fraction of the important questions have been investigated. For example, speech recognition is often recommended for use by individuals with PI, but little is known about how these potential users actually interact with this technology. At present, a single study as been reported that evaluated the use the speech recognition by individuals with PI for dictation-oriented activities (Sears et al., 2001). The opportunities for additional research are unlimited.

Unfortunately, conducting informative studies including individuals with PIs can be difficult. Unlike traditional computer users with no PIs, the pool of potential participants is limited. Even when appropriate participants can be found, additional factors can make such studies difficult. For example, individuals with PIs may need more frequent breaks, may be able to participate for less time, and may find it more difficult to arrange transportation to the site where the study is occurring. Finally, carefully documenting health conditions and the associated PIs often requires adding a physician, an occupational therapist, or both to the research team.

Although additional research is needed, the existing literature does provide insights that can prove useful to both practitioners and researchers. Individually, the articles highlight the potential benefits and limitations of various technologies for specific groups of individuals as well as new technologies that may prove useful for specific tasks or individuals in the future. When viewed as a whole, several lessons that extend beyond the technology or user groups studied become clear. We conclude by highlighting four such lessons, emphasizing the potential of new technologies that will provide alternative methods of interacting with computers, and stressing the need for additional research investigating the potential benefits as well as the limitations of existing technologies.

PI Does Not Imply Disability

Impairments can, but do not always, result in disabilities (see Fig. 25.1). Several of the studies discussed earlier demonstrate this fact. Casali (1992) included three groups of participants including individuals with PIs resulting in low motor skills, PIs resulting in high motor skills, and no PIs. In this study, the high motor skills group was able to complete cursor manipulation tasks just as quickly as the group with no PIs. This suggests that the high motor skills group did not experience any disability as a result of their PI. The authors did not provide detailed descriptions of the PI experienced by the individuals in this group or their residual motor skills, but these results clearly indicate that it is possible for PIs to be sufficiently mild such that they will not interfere with certain computing activities.

Similarly, Sears et al. (2001) described a study where individuals with high-level spinal cord injuries were able to compose text just as quickly as individuals with no PIs. These results also demonstrate that PI do not automatically translate into disabilities. Casali (1992) showed that the severity of the PI can influence whether an individual experiences a disability. In contrast, these results show that even severe PI do not result in disabilities if interfaces are designed appropriately. Several other studies provided additional evidence that technology can reduce or eliminate disabilities resulting from PIs (e.g., Keates, Langdon, et al., 2000).

PIs Affect Cognitive, Perceptual, and Motor Activities

PIs are expected to affect an individual's ability to complete basic motor activities but are not necessarily expected to affect performance on cognitive and perceptual activities. Many of the articles discussed above confirm differences in performance for motor activities (e.g., LoPresti et al., 2000; Radwin et al., 1990), More important, the unexpected affect of PIs on cognitive and perceptual activities become apparent when analyzing both fundamental interactions and the high-level strategies adopted by individuals with PIs. For example, Keates, Clarkson, and Robinson (2000) provided data showing that individuals with PIs required 18% longer to complete basic cognitive activities and 25% longer for basic perceptual activities.

Koester and Levine (1994) provided an interesting and practical example of the potential consequences of focusing on motor activities without simultaneously addressing cognitive and perceptual activities. Word prediction is often recommended for individuals with PI because it reduces the number of keystrokes they must enter. Interestingly, Koester and Levine found that each keystroke took longer when using word prediction software, especially for the individuals with PI. Since the physical actions did not change, they attribute this increase in keystroke time to unspecified cognitive factors. They also found that individuals with PI spent longer than individuals with no PI when scanning the list of possible words. As a result, word prediction actually resulted in substantial decreases in data-entry rates when compared with data entry that was not assisted by word prediction.

Differences in high-level strategies are also evident. Sears et al. (2001) found that individuals with and without PIs responded differently when using the same speech recognition system to accomplish the a variety of tasks. Individuals with PIs interrupted their dictation more often, spent a greater percentage of their time dictating as opposed to issuing commands, and navigated shorter distances. The results reported by Koester and Levine (1994) also highlight how differences in performance for basic cognitive, perceptual, and motor activities translates into differences for higher level strategies. In their study, individuals with and without PIs interacted with word-prediction software using two alternative interaction strategies. Individuals with PIs were faster when using the first strategy, whereas individuals with no PIs were faster using the second strategy. These differences can be traced directly to the differences reported earlier for basic activities such as entering keystrokes and scanning lists of alternative words.

These studies confirm the importance of integrating individuals with PIs into the process when designing new computer systems. Although existing models of computer user behavior tend to be based on results from traditional computer users with no PI, it is clear that new models based on the performance of individuals with PIs will prove more accurate (Koester and Levine, 1994). These new models must address differences not only for motor activities, but for cognitive and perceptual activities as well.

Basic Actions Can Be Difficult

A number of articles highlight the difficulty individuals with PIs may experience with even the most basic interaction activities. Trewin and Pain (1999) highlighted a variety of difficulties with activities as fundamental as pressing keys on a keyboard. Their results also highlighted numerous difficulties using a mouse. Dragging objects was difficult, as were activities that required multiple mouse clicks, but these actions can be difficult for individuals without PI as well (Franzke, 1995; MacKenzie, Sellen, & Buxton, 1991). More important, other actions that are normally relatively easy, such as pointing and clicking on objects also resulted in difficulty. Casali (1992) also illustrated the difficulty individuals with PIs can have with activities that require the mouse button to be held down while dragging the mouse. This same article highlighted a simple accommodation that helped reduce these difficulties: A simple toggle switch was provided that allowed users to avoid holding the mouse button during dragging operations. Similarly, Evans et al. (2000) provides insights that may help reduce the difficulties that individuals with PIs experience with some of these basic actions. Although many head-pointing devices emulate a mouse, their results indicate that an implementation that emulates a joystick may prove more effective because it provides a neutral resting position that allows the user to rest while the cursor does not move. This may prove particularly useful given the difficulty individuals with PI experience holding the cursor still while clicking the mouse button (Trewin & Pain, 1999).

Unfortunately, these difficulties become even more significant as target of the action gets smaller (Casali, 1992). Radwin et al. (1990) showed that performance with head-controlled devices was affected by target size even more than the mouse. As a result, individuals with PIs that use head-controlled devices would be expected to experience substantial difficulties as target sizes decrease. At the same time, careful use of force feedback in the form of gravity may help reduce these difficulties (Keates, Langdon, et al., 2000).

Standardized Descriptions of Health Conditions and PIs

Perhaps the greatest hindrance for both practitioners and researchers is the lack of accepted standards for describing the capabilities and limitations of study participants. For studies including traditional computer users with no PI, we typically provide basic demographics such as age, gender, and computer experience.

For these users, we typically assume "normal" perceptual, cognitive, and motor abilities. Occasionally, researchers even may report that participants all had "normal" or "corrected to normal" vision or hearing if these abilities are particularly relevant for a given study. For individuals with PI (or cognitive or perceptual impairments for that matter), we can no longer assume that the individual's perceptual, cognitive, and motor abilities are "normal."

Unfortunately, existing studies rarely provide sufficient details regarding health conditions or associated PIs. Many articles simply list a health condition for each participant (e.g., CP, choreoathetoid CP, incomplete SCI at C6, Friedrich's ataxia). This provides a general sense as to the PIs that may exist but does not provide a detailed understanding of the participants' abilities and limitations. Trewin and Pain (1999) do provide a brief description of each participant. A typical description included a health condition, an informal description of the associated impairment, and, for many participants, a description of their normal interactions with computers. Sears et al. (2001) described the health condition of their study participants as well as the resulting PI.

When a health condition results in a well-defined set of PIs, a precise description of the underlying health condition may be sufficient. For example, an SCI at or above C5 with an ASIA score of A or B results in paralysis of the muscles used to control the arms and legs. Given this health condition, we know that an individual would not be able to use his or her hands or arms when interacting with a computer. In contrast, a SCI at or above C5 with an ASIA score of C or D results in much more ambiguous PIs. Similarly, indicating that an individual has CP provides general insights, but the resulting PIs can vary dramatically, as noted earlier. PIs can also change with time. Some PIs are not present initially, others are progressive or regressive, and in still other situations the severity of the PI is variable. When a health condition does not map to a precise set of PIs, it is critical to describe both the health condition and the resulting PIs (and any other impairments that may affect interactions with computers).

Health conditions are best described by physicians. Physical examinations can often provide the necessary information, but access to medical records may be sufficient. Ideally, a standardized scale will be used to describe the health condition. For example, the ASIA scale can be used to describe the completeness of a spinal cord injury. Such assessments focus on the status of the individuals health, not necessarily on their physical abilities. Although these assessments focus on an individual's current status, they also provide insights into changes that may occur in the future. Most of the time, health conditions do not map directly to a well-defined set of PI. In these situations, it is recommended that an occupational therapist become involved in assessing each participant's PI. Occupational therapists can evaluate specific skills or abilities, including sensory motor, cognitive, and motor skills. The primary focus should be on those skills and abilities that may affect the individual's ability to interact with computers. Numerous standardized tests exist. Assessments by occupational therapists focus on the impairments that may affect an individual's ability to perform certain activities without regard to the underlying health condition. These assessments focus on an individual's current status and therefore do not address changes that may occur because of the progression of a disease.

Future Directions

The existing literature highlight the potential benefits and limitations of various technologies for specific groups of individuals, provide examples of situations in which PIs do not result in disabilities, illustrate the potential impact of PIs on cognitive, perceptual, and motor activities, confirm the difficulties that individuals with PIs may experience with basic actions (e.g., pressing keys and clicking the mouse button) and with more complex actions, and reenforce the need for standardized descriptions of health conditions and PIs.

This same literature confirmed the potential of various new technologies, whereas highlighting the need for additional research. Several studies illustrated the use of body parts that are normally ignored when designing computer interfaces (e.g., Shaw et al., 1995; Salem & Zhai, 1997). Others explored the potential of using electrophysiological data to control computers (e.g., Doherty et al., 2000, Kennedy et al., 2000; Kübler et al., 1999). These studies were exploratory, but they highlight the potential of these new technologies, especially for individuals with severe PIs.

We must continue to explore technologies that support alternative methods of interacting with computers, but we also need a better understanding of both the potential and limitations of existing technologies. Existing studies provide examples in which individuals with PIs were just as fast and accurate as individuals with no PIs, but important differences were apparent for satisfaction ratings as well as the strategies that the individuals with PI employed. Other studies highlighted situations in which PIs resulted in longer task completion times, higher error rates, or more subtle differences that only became apparent when performance was analyzed in detail. Future studies should attend to changes in cognitive, perceptual, and motor activities. These changes may reveal themselves through task completion times, error rates, satisfaction ratings, or through changes in the strategies that individuals adopt when completing a task. To allow both researchers and practitioners to more effectively interpret and generalize the results of such studies, we must carefully document both the health condition and the PI of study participants.

Although research into the efficacy of various technologies for individuals with PI is important, studies that assess the outcomes when assistive technologies are actually used is also critical (Fuhrer, 2001). Research studies highlight the potential of a technology but do not guarantee its success when used in the field. Outcomes research will ultimately determine the success or failure of the technologies developed by the HCI community for individuals with PIs. As a result, it is important for HCI researchers and system developers to work closely with those rehabilitation professionals who evaluate the needs of individuals with PIs, determine which technologies they should be using, and assess the success for failure of these technologies.

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